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Dust emissions from a tunnel-ventilated broiler poultry shed with fresh and partially reused litter

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Abstract. Dust emissions from large-scale, tunnel-ventilated poultry sheds could have negative health and environmental impacts. Despite this fact, the literature concerning dust emissions from tunnel-ventilated poultry sheds in Australia and overseas is relatively scarce. Dust measurements were conducted during two consecutive production cycles at a single broiler shed on a poultry farm near Ipswich, Queensland. Fresh litter was employed during the first cycle and partially reused litter was employed during the second cycle. This provided an opportunity to study the effect that partial litter reuse has on dust emissions. Dust levels were characterised by the number concentration of suspended particles having a diameter between 0.5 and 20 µm and by the mass concentration of dust particles of less than 10 µm diameter (PM_{10}) and 2.5 µm diameter ($PM_{2.5}$). In addition, we measured the number size distributions of dust particles. The average concentration and emission rate of dust was higher when partially reused litter was used in the shed than when fresh litter was used. In addition, we found that dust particles emitted from the shed with partially reused litter were finer than the particles emitted with fresh litter. Although the change in litter properties is certainly contributing to this observed variability, other factors such as ventilation rate and litter moisture content are also likely to be involved.

Introduction

The Australian poultry industries are dominated by large-scale, intensive production facilities for both chicken meat and eggs. Warm Australian weather dictates that these sheds be well ventilated to ensure that bird comfort and production efficiency are maintained. Modern poultry sheds are tunnel-ventilated, with electronically controlled mechanical ventilation systems. These sheds are typically long and narrow and capable of housing 30 000–45 000 birds. Basically, large fans on one of the narrow faces draw air from ventilation inlets at the opposite end of the shed. This creates a longitudinal airflow through the shed, which is very effective in regulating perceived temperature, even on very hot summer days. However, one possible adverse side effect of the tunnel-ventilation method is increased generation and emission of poultry dust from the sheds to the surrounding environment.

Dust emissions from tunnel-ventilated poultry sheds can potentially have negative health and environmental impacts. Dust, or particulate matter (PM), can impair visibility and contaminate or coat machinery, masonry and crops. If particulate matter is consistently inhaled by humans, it can lead to a range of respiratory and cardiovascular diseases. The severity of dust-related health effects is strongly influenced by dust particle size. Dust particles larger than 10 µm in diameter tend to settle in the human nose or throat before they can be inhaled deep into the lungs, whereas dust particles smaller than 10 µm (known as the PM_{10} size fraction) are capable of travelling further down the airway. In epidemiological studies, the PM_{10} size fraction has been strongly associated with increases in the prevalence of respiratory symptoms (e.g. asthma, bronchitis), hospital admissions and mortality (Pope *et al*. 1995). Recent evidence has suggested that smaller dust particles in the $PM_{2.5}$ or PM_1 size fractions (particles smaller than 2.5 µm and 1 µm, respectively) are even more damaging to human health because they can penetrate further into the lung (WHO 2003). In addition, these fine particles can remain suspended in the atmosphere for long periods of time (~days) and travel large distances from their sources.

The composition of dust is also an important factor in dust-related health effects. One study has found that dust emitted from tunnel-ventilated broiler (meat chicken) sheds can contain both harmless and pathogenic bacteria (Blackall *et al*. 2008). Fortunately, the emission of pathogenic bacteria was rare and concentrations were generally too low to cause any significant effects on human health. Dust is also an effective vehicle for odorous chemicals (Hammond *et al*. 1981; Heber *et al*. 1988; Oehrl *et al*. 2001; Das *et al*. 2004; Cai *et al*. 2006). Thus, it plays a large but currently uncertain role in the emission of nuisance

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odours from large-scale poultry sheds. This has been long recognised by the Australian poultry industry (Pollock and Anderson 2004). Taken together, health, environmental and odour considerations provide the motivation for studying dust emissions from large-scale, tunnel-ventilated poultry sheds in Australia.

Poultry dust emissions occur due to two general processes. First, animal activity or the movement of air causes the mechanical breakdown and subsequent entrainment into the air of mineral and organic material from birds, manure, feed and litter. Second, gaseous emissions may be converted to the particle phase under the right conditions, adding to the total dust emissions from a poultry shed. There are many interdependent factors that may influence dust levels in a poultry shed, including ventilation rate, shed design, litter properties, feed properties, stage of production (bird number and size), bird activity and shed microclimate (e.g. temperature, humidity). These and additional factors combine in complex ways to create large variability in measured poultry dust concentrations and emissions.

Dust emissions from poultry sheds have been investigated and measured for at least three decades in the USA, Europe and Australia. However, only a limited number of studies have measured dust emissions from tunnel-ventilated poultry sheds in Australia (Banhazi *et al*. 2003; Pollock and Anderson 2004) or overseas (Redwine *et al*. 2002; Visser *et al*. 2006; Fabbri *et al*. 2007). The Australian studies measured in-shed dust concentrations in the range 2.3–16 mg/m^3 for total suspended particles, 1.6–6.3 mg/m^3 for PM_{10} particles and 0.3–1.8 mg/m^3 for respirable particles (particles smaller than ~5 μm). The corresponding emissions rates from the sheds were in the range 54–1230 mg/s for total suspended particles, 17–139 mg/s for PM_{10} particles and 10–100 mg/s for respirable particles.

Here, we report dust concentrations and emission rates from a single tunnel-ventilated broiler shed on a poultry farm near Ipswich, Queensland, during two consecutive production cycles. For the first batch, fresh wood shavings were employed as the bedding material. Half of this litter was then reused for the second batch. Therefore, the present study provided an excellent opportunity to study the effect that partial litter reuse has on dust emissions, while also adding to the scarce literature concerning dust emissions from tunnel-ventilated sheds.

Materials and methods

Sampling program

The objective of broiler farms is to grow day-old chickens until they can be harvested for chicken meat. This production cycle typically takes 56 days. The first harvest or pick-up of birds usually occurs on about Day 35. From Day 35 to Day 56, multiple pick-ups occur until all the birds are harvested. For the shed investigated here, ~40 000 mixed-sex, Cobb500 breed birds were placed at the beginning of each cycle. Dust was sampled during two consecutive cycles. The first batch of birds was raised on fresh litter (wood shavings) from 31 January to 27 March 2007 and the second batch was raised on partially reused litter from 10 April to 5 June 2007.

Dust samples were collected at similar stages during both production cycles so the average results could be compared. Sampling was conducted at the following bird ages (in days) during both cycles: 14, 21, 28, 35 (or just before the first pick-up), 37 (or just after the first pick-up), 42, 49, as well as on Day 55 of Batch 2. During each sampling day, samples were collected continuously for ~2–4 h in the morning.

Sample collection

Dust measurements were conducted externally in the exhaust airstream of the broiler shed. A temporary polyethylene sampling duct (length 15 m) was designed in accordance with AS 4323.1:1995 (Standards Australia 1995*a*) and attached to an exhaust fan (1.37 m diameter) on the shed. Samples were drawn from the duct at a distance of eight duct diameters (11 m) from the fan face. Samples were obtained by drawing air through an isokinetic sampling probe that was inserted into the polyethylene duct. The isokinetic sampling probe obtained representative dust samples independently of the dust particle-size distribution. It was designed in accordance with AS4323.2:1995 (Standards Australia 1995*b*).

No measurements of shed input air were conducted during the present study. This is because background dust concentrations in the Ipswich region are generally only a small fraction of typical broiler shed dust concentrations. Rather, it was judged more important that the limited number of instruments be used to comprehensively characterise the total dust emissions from the shed by measuring different dust-size fractions. Daily measurements from the Flinders View air quality monitoring station operated by the Queensland Department of Environment and Resource Management indicated that background dust concentrations in the Ipswich region were less than 10% of the dust concentrations measured in the exhaust air of the poultry shed during the present study (http://www.derm.qld.gov.au/environmental_management/air/index.html, verified 17 February 2010).

Dust instrumentation

Dust levels were characterised by both the mass of dust particles per m^3 of air (particle mass concentration) and the number of dust particles per m^3 of air (particle number concentration). In addition, the size distributions of dust particles over the range 0.5–20 μm were also measured. Particle mass concentration was measured for two size fractions, PM_{10} and $PM_{2.5}$, using two TSI model 8520 DustTraks (http://www.tsi.com) with appropriate inlets. Particle number concentrations and size distributions were measured with a TSI model 3320 Aerodynamic Particle Sizer (APS). All three dust instruments (two DustTraks and one APS) were operated in parallel downstream of the isokinetic sampling probe. They measured continuously in real-time, recording mass concentrations every 30 s and number concentrations and size distributions every 20 s.

Measurement of other relevant parameters

The ventilation rate of air through the shed was obtained by measuring in-shed and at-the-fan airspeeds with a hot-wire anemometer (VelociCalc Model 8386-M-GB; TSI), and by calculating the flow rate through each active fan by using manufacturer supplied fan flow rate data adjusted for shed static pressure. Data reported in the present paper were obtained by the latter method as it was found to be more consistent and accurate than the former method. Ambient temperature and relative humidity were measured with a Kestrel Pocket Weather Tracker (Model 4500, Nielsen–Kellerman, Boothwyn, PA, USA). Various production parameters, including number of birds placed, number of birds present on each sample collection day and average daily liveweight, were supplied by the farm manager and integrator.

Data processing

Dust emission rates (mg/s or no. of particles/s) were calculated by multiplying measured dust concentrations (mg or particles/m^3) by corresponding shed ventilation rates (m^3/s). These rates represent the mass or number of dust particles emitted per second from the exhaust of the poultry shed. Emission rates were further normalised by the number of birds placed or the live bird weight in the shed to enable comparison between the results as well as comparison with other studies. A very large number of dust particle-size distributions were collected during the study. To simplify this large dataset and obtain useful information, we calculated one parameter – count median diameter (CMD) – from these distributions. CMD refers to the midpoint diameter of a particle number size distribution.

Although dust was measured continuously throughout the sample collection periods and on seven or eight different days during a production cycle, we have chosen to report here only the averages of all concentration, emission rate and CMD measurements for each production cycle. This is because the aim of the present paper is to examine the effect that partial litter reuse has on dust emissions. Subsequent papers will introduce additional data to examine how other factors such as ventilation rate, bird age and season can affect dust emissions from tunnel-ventilated poultry sheds.

Results

The conditions during dust sampling for both production cycles are displayed in Table 1. The first batch of chickens was raised on fresh litter from summer to autumn and the second batch was raised on partially reused litter from autumn to winter. This seasonal difference was reflected by higher ambient temperatures during Batch 1 than those during Batch 2. Relative humidity was fairly constant for both sampling periods. More birds were placed on the fresh litter than on the partially reused litter and, on average, the total live bird weight throughout the production cycle was also greater for the first batch. The average shed ventilation rate and litter moisture content were also greater during the slightly hotter fresh-litter period.

Table 1. Average values and standard deviations (parentheses) of conditions during dust sampling with fresh and partially reused litter

Litter type	Fresh	Partially reused
Cycle period	31 Jan.–27 Mar.	10 Apr.–5 Jun.
Birds placed	40 457	37 193
Average total live bird weight (kg)	54 131 (18 355)	51 895 (12 425)
Average ambient temperature (°C)	27.95 (1.45)	24.76 (2.78)
Average relative humidity (%)	58.4 (7.6)	58.1 (12.5)
Average ventilation rate (m^3/s)	83.3 (19.9)	67.0 (13.4)
Average litter moisture content (%)	29.7 (4.9)	26.7 (2.1)

Fig. 1 compares the averages of all dust measurements [PM_{10}, $PM_{2.5}$ and particle number (PN)] taken during both production cycles. Dust concentrations are represented by the white columns and emission rates are represented by the grey columns. Emission rates are expressed in units of mass or number of particles emitted per second per 1000 birds placed, to enable a better comparison between the two cycles that began with different numbers of birds (40 457 *v.* 37 193, see Table 1). Average dust concentrations for all three dust variables increased when partially reused litter was used in the shed. The relative increase in the number of dust particles was greater than the increase in the mass of dust particles. Average PN concentration with partially reused litter was 3.1 times greater than the average concentration with fresh litter, whereas average PM_{10} and $PM_{2.5}$ concentrations with partially reused litter were only 1.6 and 1.4 times greater than the fresh-litter values, respectively. The same trend was observed for the average dust emission rates. Some studies express dust emission rates per kg live bird weight in the shed. For comparison with these studies, the average emission rates expressed on this basis are provided in Table 2.

The average count median diameters during the fresh and partially reused litter cycles are displayed in Fig. 2. These values mean that, on average, half of the dust particles sampled when fresh litter was used in the shed were smaller than 2.46 μm in diameter and half of the dust particles sampled when partially reused litter was in the shed were smaller than 1.85 μm. Therefore, smaller dust particles were produced with partially reused litter.

Discussion

Wood shavings were employed as the litter material in this shed. Fresh wood shavings are quite large (about a few cm). During a production cycle, bird movement abrades these wood shavings into very fine pieces. This means the partially reused litter was composed of a greater number of smaller pieces of wood shavings than the fresh litter. It might be expected that dust generated from this finer litter will also be composed of finer particles and our measurements suggest that this is indeed the case (Fig. 2). Fine dust particles can remain suspended in the atmosphere for long periods of time and evidence has shown that they are more damaging to human health than are coarse particles.

In addition to affecting dust particle size, it appears that partially reusing litter can increase dust levels and emissions from a tunnel-ventilated poultry shed (Fig. 1). However, it should be noted that although some of the factors likely to influence poultry dust emissions (shed design, stage of production, feed properties) were partially controlled in these

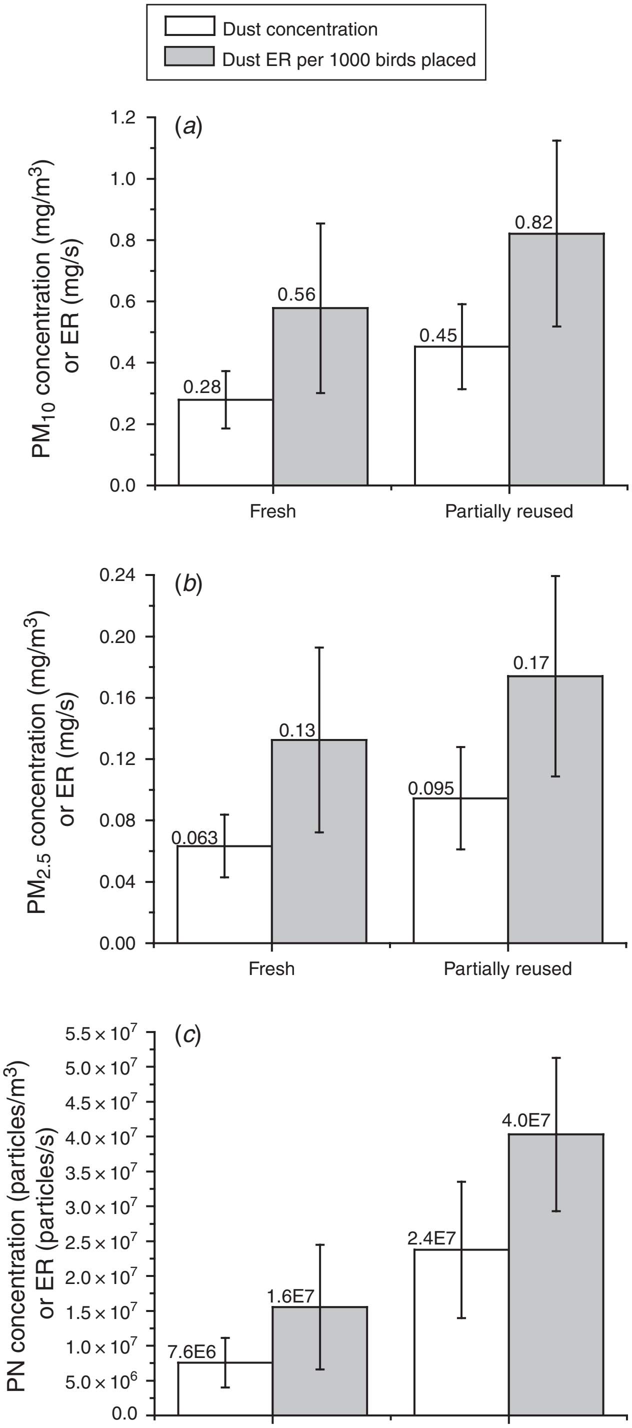

Fig. 1. Comparison of average dust concentrations (white columns) and emission rates (ER) (grey columns) for sampling periods with fresh and partially reused litter. Dust is characterised by the mass of dust particles smaller than (*a*) 10 µm diameter (PM_{10}), (*b*) 2.5 µm ($PM_{2.5}$) and (*c*) between 0.5 and 20 µm (PN). Dust ER are expressed per 1000 birds placed at the beginning of each production cycle. Values on the columns represent the plotted averages and error bars represent 1 s.d. of all measurements taken during each sampling period.

Table 2. Average dust emission rates (and s.d. in parentheses) per kg live bird weight

Dust variable	Fresh	Partially reused
PM_{10} (mg/s.kg)	$4.7\ (1.7) \times 10^{-4}$	$6.2\ (2.3) \times 10^{-4}$
$PM_{2.5}$ (mg/s.kg)	$1.1\ (0.4) \times 10^{-4}$	$1.3\ (0.3) \times 10^{-4}$
Particle no. (particles/s.kg)	$1.2\ (0.5) \times 10^{4}$	$3.2\ (1.6) \times 10^{4}$

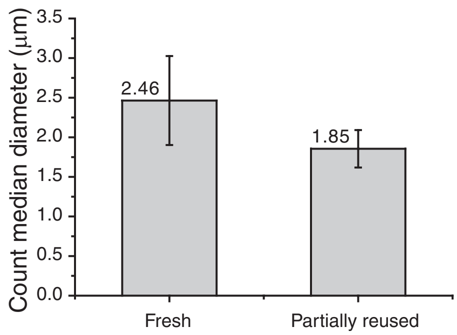

Fig. 2. Comparison of average count median diameter for dust particles sampled with fresh and partially reused litter used in the shed. Values on the columns represent the plotted averages and error bars represent 1 s.d. of all measurements taken during each sampling period.

experiments, it was not possible to control all of them (e.g. ventilation rate, microclimate, bird activity). Ventilation rate and litter moisture content, in particular, were different during each of the production cycles (Table 1). This is likely to contribute to some of the variability observed in Figs 1 and 2. For example, the drier litter conditions during the second batch period may have enhanced the entrainment of fine dust into the shed air, causing an increase in dust levels and decrease in average particle size. Nevertheless, even when these additional factors are taken into account, it seems reasonable to conclude from these data that partially reusing litter tends to increase the amount and decrease the size of dust emitted from poultry sheds.

Care needs to be taken when comparing dust measurements from separate studies as differences in sampling methodologies and instrumentation can translate into significant differences in measured dust levels and emission rates. Of the studies that have investigated dust emissions from tunnel-ventilated poultry sheds in Australia (see Introduction), only one reported a dust variable (PM_{10}) that was also measured in the present study (Mirrabooka 2002, cited in Pollock and Anderson 2004). The Mirrabooka 2002 study was conducted at two tunnel-ventilated sheds on a farm near Tamworth. The authors conducted weekly measurements over an entire production cycle and found PM_{10} concentrations in the range 1.6–6.3 mg/m^3 and PM_{10} emission rates per 1000 birds placed in the range 0.63–5.1 mg/s. The fresh and partially reused litter average PM_{10} values measured in the present study are either below or at the very bottom of these ranges. We cannot find sufficient details of the sampling methodology used in the Mirrabooka 2002 study to speculate on the difference in the results.

Conclusion

Dust was measured in the exhaust air of a tunnel-ventilated broiler shed during two consecutive production cycles. During the first cycle, fresh wood shavings were employed as the bedding material. Half of this litter material was then reused during the second production cycle. On average, dust concentrations in the air exiting the shed and dust emission rates from the shed were higher with partially reused litter than with fresh litter. In addition, the dust particles emitted during the partially reused litter batch were smaller than the particles emitted during the fresh-litter batch. It is likely that some of these differences can be attributed to the different litter properties during the two cycles. However, differences in ventilation rate and litter moisture content probably also contributed to the variability observed.

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